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Role of Municipal Wastewater Treatment in Control of Toxics

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THE ROLE OF MUNICIPAL WASTEWATER TREATMENT IN CONTROL OF TOXICS

by

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16. ABSTRACT

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INTRODUCTION

In the past, municipal wastewater treatment systems have been designed to support three principal pollution control roles:

- Control of gross organics (BOD_5), suspended solids, and other gross pollutants.
- Control of nutrients.
- Control of bacteria and other pathogens.

Indeed, an extensive array of control technology has been developed ranging from the physical removal of floatables, grit and other solids to advanced biochemical and physical-chemical processes capable of renovating municipal wastewater to essentially potable quality. Today, a wide spectrum of innovative and alternative municipal technologies (1) are also being applied to reduce costs and energy requirements for these pollution control objectives and thus to meet more effectively the important environmental goals of clean and useful water.

In all municipal control technology, a fourth role has always been occurring but usually has not occupied a well recognized or design controlling position. The fourth role is the control of toxics entering the municipal collection and treatment systems. In the United States, the control of chemical toxics released into the environment through wastewater discharges can be achieved, by conservative choice, through the use of industrial treatment or pretreatment to limit the amounts of such materials before release directly to the environment or to the municipal wastewater systems. The use of "end of the pipe" technology by industry to control their discharges, however, involves substantial costs. Thus, industry has also begun extensive assessments of in-plant modifications to minimize or eliminate the costs of "end of the pipe" control. A second alternative to industrial treatment or pretreatment is also available; that is, the use of the central municipal treatment plant when acceptable treatment and control of these toxic substances can be achieved.

With the limited resources available for control of water pollution and the increasing complexity of the waste loads from modern urban centers, the use of the central municipal treatment plant for cost-effective control of toxics is essential and will become an increasingly important function for municipal wastewater treatment. The purpose of this presentation is to provide an overview of the performance of municipal treatment systems for control of toxics and thus to project future research and development challenges for more effective use of the central municipal treatment plant for toxics control.

RESEARCH ON TOXICS CONTROL

As previously reported to this committee, research and development on toxics control in municipal wastewater treatment in the United States consists of a three tier approach:

- Survey monitoring to assess the toxics loads in municipal wastewaters.
- Treatability research to evaluate the specific treatment mechanisms for removal of toxics.
- Removability research with supporting studies on fate of toxics during disposal to assess the integrated capabilities of municipal treatment plants for control of toxics.

The planned work in the first area is essentially completed. Substantive work is ongoing in the other two areas. Before reviewing the current major findings of this research and development effort, a listing of the principal removal mechanisms and the principal classes of substances for toxic control in municipal wastewater treatment is desirable. The removal of specific toxics in conventional municipal wastewater treatment occurs chiefly through three important mechanisms:

- Adsorption, or partitioning on, and removal with the solids in the treatment processes.
- Biodegradation.
- Stripping or volatilization of the purgeable toxics.

In alternate treatment systems, two additional important mechanisms are:

- Adsorption on granular activated carbon.
- Chemical precipitation.

In order to conveniently assess the research findings, the wide variety of U.S. EPA priority toxics known as priority pollutants (2) have been divided into classes as shown in Table 1. Other toxics may also be important but as yet have not received extensive study in EPA municipal wastewater research.

The needed detailed understanding of the specific removal mechanisms (treatability) in relation to the cumulative removal of all removal

TABLE 1. PRIORITY TOXICS IN PLANT EFFLUENTS

Class of Toxics	Secondary Effluent		
	No. of effs.[a]	Max. Conc. µg/l	Detection Frequency
Inorganics			
Antimony (total)	48	75	0.85
Arsenic (total)	44	50	0.84
Asbestos (total)	--	NM[c]	NM[c]
Beryllium (total)	47	4	0.64
Cadmium (total)	52	83	0.92
Chromium (total)	54	2096	1.00
Copper (total)	53	4567	0.96
Cyanide (total)	40	4462	0.98
Lead (total)	54	558	0.91
Mercury (total)	39	10	0.92
Nickel (total)	50	865	0.96
Selenium (total)	42	50	0.91
Silver (total)	53	36	0.74
Thallium (total)	41	100	0.20
Zinc (total)	54	3742	1.00
Halogenated Aliphatics			
Methane, bromo	52	38	0.12
Methane, chloro	52	340	0.29
Methane, dichloro	49	630	0.90
Methane, tribromo	52	5	0.12
Methane, trichloro	50	30	0.84
Methane, tetrachloro	51	28	0.31
Methane, chlorodibromo	52	5	0.15
Methane, dichlorobromo	51	36	0.31
Methane, trichlorobromo[b]	xx	ND	0.00
Methane, dichlorodifluoro	50	99	0.14
Ethane, chloro	52	15	0.12
Ethane, 1,1-dichloro	52	5	0.37
Ethane, 1,2-dichloro	52	119	0.42
Ethane, 1,1,1-trichloro	52	224	0.71
Ethane, 1,1,2-trichloro	52	5	0.15
Ethane, 1,1,2,2-tetrachloro	52	5	0.21
Ethane, hexachloro	54	8	0.09
Ethene, chloro	52	101	0.19
Ethene, 1,1-dichloro	52	5	0.19
Ethene, 1,2-trans-dichloro	52	8	0.35
Ethene, trichloro	52	674	0.81
Ethene, tetrachloro	51	134	0.84
Propane, 1,2-dichloro	51	5	0.33
Propene, 1,3-dichloro	52	5	0.06
Butadiene, hexachloro[b]	xx	ND[c]	0.00
Cyclopentadiene, hexachloro[b]	xx	ND[c]	0.00

(continued)

TABLE 1. PRIORITY TOXICS IN PLANT EFFLUENTS (Continued)

Class of Toxics	Secondary Effluent		
	No. of effs.[a]	Max. Conc. µg/l	Detection Frequency
Halogenated Ethers			
Bis(2-chloroethyl) ether[b]	xx	ND[c]	0.00
Bis(2-chloroisopropyl) ether[b]	xx	ND[c]	0.00
2 Chloroethyl vinyl ether[b]	xx	ND[c]	0.00
Bis(2-chloroethoxy) methane[b]	xx	ND[c]	0.00
4-Chlorophenyl phenyl ether[b]	xx	ND[c]	0.00
4-Bromophenyl phenyl ether[b]	xx	ND[c]	0.00
Monocyclic Aromatics			
Benzene	47	19	0.70
Benzene, ethyl	51	45	0.63
Benzene, chloro	51	16	0.29
Benzene, 1,2-dichloro	54	64	0.48
Benzene, 1,3-dichloro	53	113	0.36
Benzene, 1,4-dichloro	54	18	0.56
Benzene, 1,2,4-trichloro	54	37	0.22
Benzene, hexachloro	54	20	0.07
Benzene, nitro	54	1	0.13
Toluene	47	408	0.81
Toluene, 2,4-dinitro	54	20	0.07
Toluene, 2,6-dinitro	54	25	0.02
Nitrogenous Organics			
Acrylonitrile	54	100	0.07
Nitrosamine, dimethyl	54	ND[c]	0.00
Nitrosamine, diphenyl	54	4	0.09
Nitrosamine, di-n-propyl	54	37	0.20
Benzidine	54	20	0.02
Benzidine, 3,3'-dichloro	54	1	0.04
Hydrazine, 1,2-diphenyl	54	10	0.17
Pesticides			
Acrolein	54	ND[c]	0.00
Aldrin	50	11.1	0.24
α-BHC-Alpha	48	3.8	0.35
β-BHC-Beta	54	4.2	0.24
γ-BHC(lindane)-Gamma	47	5.2	0.60
δ-BHC-Delta	51	3.6	0.24

(continued)

TABLE 1. PRIORITY TOXICS IN PLANT EFFLUENTS (Continued)

Class of Toxics	Secondary Effluent		
	No. of effs.[a]	Max. Conc. µg/l	Detection Frequency
Chlordane	54	0.03	0.02
4,4'-DDT	51	1.02	0.16
4,4'-DDE(p,p'-DDX)	49	0.20	0.16
4,4'-DDD(p,p'-TDE)	52	0.60	0.19
Dieldrin	50	0.15	0.20
α-endosulfan-Alpha	42	ND[c]	0.00
β-endosulfan-Beta	43	0.05	0.02
Endosulfan sulfate	52	4.8	0.02
Endrin	53	0.43	0.13
Endrin aldehyde	54	0.24	0.09
Heptachlor	50	1	0.38
Heptachlor epoxide	52	0.9	0.23
Isophorone	54	25	0.07
Phenolics			
Phenol	53	300	0.74
Phenol, 2,4-dimethyl	54	25	0.26
Phenol, 2-chloro	54	1	0.15
Phenol, 2,4-dichloro	54	50	0.32
Phenol, 2,4,6-trichloro	54	50	0.22
Phenol, pentachloro	53	250	0.51
Phenol, 2-nitro	54	12	0.15
Phenol, 4-nitro	54	15	0.02
Phenol, 2,4-dinitro	54	50	0.04
m cresol, p-chloro	54	50	0.17
o cresol, 4,6-dinitro	54	< 1	0.02
Phthalates			
Phthalate, dimethyl	54	50	0.28
Phthalate, diethyl	54	54	0.83
Phthalate, di-n-butyl	54	84	0.98
Phthalate, di-n-octyl	54	10	0.32
Phthalate, bis(2-ethylhexyl)	54	396	0.91
Phthalate, butylbenzyl	54	119	0.61
Polychlorinated Biphenyls (PCBs)			
PCB-1016	55	ND[c]	0.00
PCB-1221	55	ND[c]	0.00
PCB-1232	55	ND[c]	0.00
PCB-1242	55	0.8	0.04

(continued)

TABLE 1. PRIORITY TOXICS IN PLANT EFFLUENTS (Continued)

Class of Toxics	Secondary Effluent		
	No. of effs.[a]	Max. Conc. µg/l	Detection Frequency
PCB-1248	55	ND[c]	0.00
PCB-1254	55	0.5	0.04
PCB-1260	55	ND[c]	0.00
Polynuclear Aromatic Hydrocarbons			
Acenaphthene	54	10	0.15
Acenaphthylene	54	10	0.13
Anthracene	53	20	0.43
Anthracene, benzo(a)	54	10	0.32
Anthracene, dibenzo(a,h)	54	1	0.02
Chrysene	54	10	0.36
Fluoranthene	54	20	0.41
Fluoranthene, benzo(b)	54	8	0.07
Fluoranthene, benzo(k)	54	10	0.15
Fluorene	54	15	0.19
Naphthalene	54	32	0.57
Naphthalene, 2-chloro	xx	ND[c]	0.00
Perylene, benzo(g,h,i)	54	25	0.07
Phenanthrene	54	20	0.50
Pyrene	54	30	0.39
Pyrene, benzo(a)	54	25	0.11
Pyrene, indeno(1,2,3-c,d)	54	15	0.04

[a]The number of effluents include one, or occasionally two, 24-hour composite effluent samples from each plant in the 25 Cities Survey (3) and the average of one week's samples as a composite effluent from the first 20 cities in the Effluent Guidelines Division's Survey (4). The number of effluents are variable because of lost samples or analytical difficulties.

[b]The number of effluents is approximately 50.

[c]NM means the substances was not measured in the surveys; ND means the substance was not detected in the surveys.

mechanisms (removability) on the representative toxics entering the municipal treatment plants has sufficiently evolved to permit estimation of the overall removal of a wide variety of potential toxics and thus to begin providing a sound engineering approach for the control of toxics in municipal treatment plants.

Survey and Monitoring Findings

Survey data from 45 municipal treatment plants (3)(4) have been analyzed to determine number and types of priority toxic pollutants that were exceeding proposed U.S. EPA water quality criteria in the plant's secondary and, in some cases, primary effluent. All samples had been analyzed for each of the original 129 EPA priority pollutants with the exception of asbestos and dioxin.

The limited residual concentrations data include typically single 24-hour composites at 25 plants (3) and average concentrations from a week's set (5-6 samples) of 24-hour composite samples from 20 treatment plants (4). Survey results on approximately 30 additional plants have been obtained but have not yet been evaluated.

The water quality criteria for the assessment were obtained from EPA's proposed values on the priority pollutants as given in the November 28, 1980 Federal Register and were divided into four categories of designated receiving water uses:

- Fresh water aquatic life criteria.
- Salt water aquatic life criteria.
- Human health-recreation (fish consumption) criteria.
- Human health-water supply (and fish consumption) criteria.

Where toxicity depended upon water hardness, a hardness of 100 mg/l of $CaCO_3$ was used to select the criteria. Algal toxicity limits were not included in the selected criteria. For the toxics where no safe limits of exposure for human carcinogens were established, limits of 1/1,000,000 based on an incremental increase of cancer risk over a lifetime were used to select the criteria for the assessment. Organoleptic criteria were not used in the assessment.

The criteria were compared to the measured values found in the plant effluents on a plant-by-plant basis, assuming no dilution and then various dilution levels corresponding to the typical dilution conditions expected for the designated water use.

The overall analysis, with specific results summarized in Table 2, revealed the following trends in the United States:

TABLE 2. PRIORITY TOXICS EXCEEDING VARIOUS WATER QUALITY CRITERIA FOR SECONDARY EFFLUENTS

Criteria	Dilution	No. of compounds with an exceedance	Avg. no. of compounds in exceedance per plant	Compounds most frequently in exceedance
Freshwater Aquatic Life	None	33	7 Inorganics 2 Pesticides 3 Phthalates 12 Total	Cu, Cd, Zn, Pb, Ag, Hg, Cyanide, Heptachlor, Lindane
	15 times	24	4 Inorganics 1 Pesticide 5 Total	Cd, Hg, Ag, Cyanide, Heptachlor
Saltwater Aquatic Life	100 times	10	1 Total	Cyanide, DDT
Human Health-Recreation	None	48	2 Inorganics 2 Pesticides 3 PAHs 1 Aliphatic 8 Total	As, Hg, Be, Heptachlor, Lindane, Phenanthrene, Anthracene, Pyrene, Chrysene, Dichloromethane
	15 times	36	1 Inorganic 2 Pesticides 3 PAHs 6 Total	As, Heptachlor, same PAHs as above
	100 times	25	1 Inorganic 1 Pesticides 2 PAHs 4 Total	Same as above
Human Health-Water Supply	5 times	50	2 Inorganics 2 Pesticides 3 PAHs 5 Aliphatics 12 Total	As, Be, Hg, Heptachlor, Lindane, same PAHs as above, Dichloromethane, Chloroform, Tetrachloroethene, Chloro-methane
	15 times	50	2 Inorganics 2 Pesticides 3 PAHs 3 Aliphatics 10 Total	Same as above

- All surveyed plant's effluents contained at least one priority toxic at a concentration which, with appropriate dilutions, exceeded a water quality criteria. Many of the priority toxic residuals exceeded at least one type of criteria.

- The "average" plant's secondary effluent exceeded the fresh water aquatic life criteria for 12 compounds without dilution and 5 compounds with a 15:1 dilution. At the 15:1 dilution, the inorganics (Cd, Hg, Ag, cyanide) and a pesticide (heptachlor) were the principal priority toxics exceeding the criteria.

- For the saltwater aquatic life criteria, at a dilution of 100:1, the "average" plant's primary effluent exceeded the criteria for two compounds; the "average" secondary effluent exceeded the criteria for only one compound; either a pesticide, usually DDT, or an inorganic, usually a cyanide. In addition, 24 of the 45 plant's secondary effluents did not exceed any criteria.

- For the human health criteria for fish consumption (recreation) the "average" plant's secondary effluent, at dilutions of 15:1 and 100:1, exceeded the criteria for six and four toxics, respectively. A metal (As), a pesticide (heptachlor) and the PAHs (phenanthrene, anthracene, pyrene and chrysene) were the principal toxics.

- For health effects criteria on fish and water consumption (water supplies), at dilution factors of 5:1 and 15:1, the average secondary effluent exceeded the criteria for 12 and 8 toxics, respectively. Metals, pesticides, PAHs and halogenated aliphatics were the principal classes of toxics exceeding the criteria.

- An average plant's primary effluent contained approximately 3 more toxics that exceeded a water quality criteria than the secondary effluent.

- The PAHs found in plant effluents consistently exceeded human criteria because the low criteria limits of 0.03 ug/l for fish consumption and 0.003 ug/l for water supplies imply that detection of the compound means exceedance of the criteria.

While four classes of toxics, inorganics (metals and CN), pesticides and PAHs and, for only the water supply criteria, halogenated aliphatics exhibited repetitive exceedances in many plant effluents, the toxics in remaining classes reveal few trends with occasional site specific exceedances of proposed criteria for any individual toxic. These site specific exceedances may correspond to specific significant industrial production or use within the urban area. However, the confirmatory industrial use data are not available.

Finally, the limited survey data, with its associated variability in quantitation, are not an effective source for estimation of plant removability of specific toxics.

Several factors reduced the quantitative certainty of the survey data for removability and fate of the toxics during municipal treatment. These factors are:

- The highly variable and low concentrations of the specific compounds in the municipal wastewater.
- The inherent analytical variability associated with measurement of parts per billion concentrations of the specific toxic compounds in presence of substantial interfering background.
- Lack of proper experimental control systems in the municipal treatment plant.

The quantitative uncertainty from these factors can be minimized by the addition of spiked amounts of representative, specific, organic pollutants to the influent of the municipal treatment systems, by providing sufficient repetitive measurements of the compounds of interest, and by using a parallel identical treatment system on the same wastewater for experimental control purposes. These corrective actions were applied to the EPA's subsequent removability research as presented later.

Treatability Research

The Municipal Environmental Research Laboratory has completed the treatability characterizations (specific removal mechanisms) of many of the individual priority toxics for static culture biodegradability (5), purgeability (6), and adsorbability on activated carbon (7). Data on liquid/solids partitioning as indicated by the octanol/water partition coefficient have also been summarized (8) for the EPA priority organics. An overview of treatability results for the classes of priority toxics is presented in Table 3. As discussed later, the treatability characterization can be used with limited removability data on representative toxics in conventional primary-activated sludge treatment to qualitatively estimate the probable removals of other toxics in primary-activated sludge treatment or in other wastewater treatment systems.

In addition to the treatability characterization in Table 3, the effects of chemical precipitation with sedimentation on spiked toxic metals (in the typically encountered forms) have also been evaluated (9). Chemical treatment (lime, iron salts or aluminum sulfate) will generally effectively remove ($\sim$ 90 percent) most of the toxic metals. Four metals, antimony as Sb^{+3}, mercury as Hg^{+2}, selenium as SeO_2^{-2}, and thallium as Tl^{+3} were not efficiently removed from municipal wastewater (typically 50 percent or less removal) by any of the three chemical systems.

Ongoing treatability work includes adsorbability studies on active biomass, studies on continuous culture aerobic biodegradability including toxic effects on the biomass, limited studies on anaerobic biodegradability and studies of chemical dechlorination of selected organic chlorine compounds (monocyclic aromatics, PCBs, and pesticides) using sodium polyethylene glycol followed by aerobic biooxidation of the dechlorinated residuals. An

TABLE 3. TYPICAL TREATABILITY OF CLASSES OF PRIORITY TOXICS

Class of Toxics	Treatability Mechanism[a]			
	Purgeability Henry's Law Constant (m^3atm/mol) x 10^{-3})	Partitioning Log Oct./water Part. Coeff.	Biodegradability[b] Static Cult. Percent Degrad.	Adsorbability[c] Freundlich X/M, mg/g
Inorganics	none-low	-	-	low-high
Halogen. Aliph.	low-high [.53 - 58.3]	low-high [1.25-3.99]	low-med. [25-100]	low-high [0.59-370]
Halogen. Ethers				
Phenyl Ethers	low	high [4.08-5.15]	low [0]	med [111-114]
Others	low-med	Low [1.28-2.58]	low-high [0-100]	low [3.9-24]
Mono. Aromatics				
Chlorobenzenes and Nitrotoluenes	low-med [0.24-3.93]	med-high [2.01-6.18]	low-high [20-89]	med-high [91-450]
All Others	med [5.55-6.44]	low-med [1.85-3.15]	med-high [49-100]	low [1-68]
Nitrogen. Organics				
Alkyl nitrosamines and Benzidenes	low	low-med [0.06-3.02]	low-med [0-27]	low-high [< 1-300]
Others	low	low-med [(-0.14)-2.57]	high [80-100]	low-high [1.4-220]
Pesticides	low-med	med-high	low	med-high
(Organochloro)	[.032-4.89]	[2.7-6]	[0]	[194-1,220]
Phthalates	low	med-high [2.12-8.73]	low-high [0-100]	med-high [97-11,300]
Polychlor. Biphenyls	low-med	med-high	low-high	high
[PCBs]	[8.37]	[2.80-6]	[0-100]	[242-630]
Polynuclear Aromatics	low	med-high	low-high	low-high
[PAHs]	[0.114]	[3.3-7.3]	[0-100]	[11-664]

(continued)

TABLE 3. TYPICAL TREATABILITY OF CLASSES OF PRIORITY TOXICS (Continued)

Class of Toxics	Treatability Mechanism[a] Purgeability Henry's Law Constant (m^3atm/mol) x 10^{-3})	Partitioning Log Oct./water Part. Coeff.	Biodegradability[b] Static Cult. Percent Degrad.	Adsorbability[c] Freundlich X/M, mg/g
Phenolics				
Unchlorinated	low [0.014]	low-high [1.46-4.09]	med-high [52-100]	low-high [21-169]
Chlorinated	low	med-high [2.95-5.01]	low-high [19-100]	low-high [51-157]
Acrolein and Isophorone	-	low [(-0.09)-1.70]	high [100]	low-high [1.2-32]
TYPE OF REMOVAL:				
Low	[≤ 3]	[2]	[0-24]	[<75]
Med	[>3-≤15]	[2-≤4]	[25-74]	[75-~250]
High	[>15]	[>4]	[75-100]	[>~250]

[a]The estimated treatability characterizations are for typical class performance. An individual toxic in any class may be outside the performance characterization range. The values in the [ ] are available measured numbers for the characterizing performance indicators (Henry's Law Constant, log octanol/water partition coefficient, percent biodegradability, and Freundlich adsorption capacity X/M). Individual toxics in any class may exhibit performance indicators outside the range of numbers provided.

[b]The percent biodegradability was determined by a modified Bunch-Chambers static culture test (5). Results presented are for original culture test without adaptation.

[c]The adsorption capacity on activated carbon, X/M, in mg/g is at pH 7 and an equilibrium organic concentration in the water of 1.0 mg/l.

interesting observation to date is that the relative adsorbability ranking of specific organic toxics on biomass is similar to that for activated carbon but with the adsorption capacity (X/M) typically an order of magnitude lower. If that observation continues to be generally consistent, the extensive toxic adsorbability data on activated carbon may be used to estimate biomass adsorbability.

Removability Research

The EPA's Municipal Environmental Research Laboratory is assessing the removability, the fate and partitioning of specific toxics, and the impact of the toxics during municipal wastewater treatment at the EPA's new Test and Evaluation Facility in Cincinnati. The basic approach features the continuous spiking of individual toxics and groups of selected toxic pollutants into the raw wastewater from the Cincinnati Mill Creek Sewage Treatment Plant. The spiked wastewater enters pilot wastewater treatment systems in which the fate and impact of the added toxics are repetitively monitored as they pass through the treatment processes. Other identical pilot systems, where appropriate as the controls, treat the unspiked Cincinnati raw wastewater.

The ongoing studies include the evaluation of:

- The fate and removal of selected priority organic pollutants (10, 11).
- The fate and removal of indigenous metals (12).
- The impact and removal of selected spiked metals (13, 14, 15, 16).
- The removal of toxicity by the treatment system as measured by the reduction in acute toxicity (17).
- The occurrence of chronic toxicity to fathead minnow embryos in the treated effluents (18).

As a practical approach, the studies on extractable (semivolatile) organics and on metals are performed in small-scale pilot systems. The studies on purgeable (volatile) organics, however, are performed in large pilot systems with representative sidewater depths.

Removal of Extractable Organics

The extractable (semivolatile) organics removability studies have been completed for conventional primary-activated sludge treatment. The pilot treatment systems were operated at a nominal SRT of 7 days, which resulted in a F/M of 0.6 kg COD applied per day per kg MLSS, or a F/M of 0.18 on a TOC basis. A comparison of the operating data between the control and spiked treatment sequences indicated that both systems were operated in essentially the same manner and were providing good treatment. Total suspended solids, COD, and TOC reductions were 95, 89, and 90 percent, respectively. The activated sludge processes produced significant ammonia-nitrogen reductions even though they were not operated to consistently nitrify.

Twenty-two semivolatile organics spiked into the raw wastewater (Table 4) were selected from those organics found in the raw wastewaters of the first 20 of the municipal wastewater treatment plants from the Effluent Guidelines Division's survey (4). A nominal spiking concentration of 50 µg/l for each single component compound was selected as representative of the concentrations found in the Survey. Since Arochlor 1254 and toxaphene were multi-component mixtures, a nominal 150 µg/l of each mixture was selected to improve their quantitation by GC/MS. Eight sets of 24-hr composite samples were analyzed by costly GC/MS procedures (19, 20 and 21) over a period of several months to provide reasonable statistical quantitation of the removability.

Most of the selected organics in the unspiked raw wastewater were found at or near the detection limits (1 to 10 µg/l) of the analytical methods. Phenol, several phthalates, and naphthalene were observed in relatively substantial concentrations in the unspiked raw wastewater. Spiking, substantially increasing the concentrations of the organics in the wastewater, permitted evaluation of the removals across the plant.

A comparison of the influent and activated sludge effluent data of the spiked system indicated that the treatment sequences were generally effective in reducing the concentrations of the organic compounds in the wastewater streams. The spiked system typically produced a more than 97 percent reduction in the concentrations of the compounds being spiked. Most of the residual concentrations of the chemicals were below the detection limits in the activated sludge effluent. Lindane, bis(2-ethylhexyl)phthalate, di-n-butylphthalate, pentachlorophenol, and phenol were found in analytically significant concentrations (4.8 to 25.8 µg/l) in the secondary effluent.

Substantial concentration increases occurred in both the primary and return activated sludges. Typically a two order of magnitude increase in concentration, based on the influent values, occurred in the primary sludge samples. Concentration increases observed in the return sludge ranged from 0.5 to 1.5 orders of magnitude depending on the specific compound.

Mass distributions (Table 4) were computed for each compound based on the mean concentrations observed in the influent, secondary effluent, primary sludge, and return activated sludge, and the operating parameters of the systems. Since most of the compounds studied are biodegradable to some extent, the probability of accounting for 100 percent of any given chemical was expected to be low; additionally, good accounting of the chemicals in the distribution balances was not anticipated due to the inherent variability in the GC/MS data. The results of the distribution calculations for the spiked system, in general, are much better than anticipated; the total percentages of the different compounds which were accounted for are reasonable.

The pesticides and PCBs partitioned approximately equally between the primary sludge and the activated sludge. A substantial portion of lindane, 55 percent, was found in the activated sludge effluent. The three phenols studied were not found to concentrate in either of the sludge streams. These data indicate that two of the phenols studied are relatively biodegradable. Pentachlorophenol substantially passed through the treatment plant.

TABLE 4. DISTRIBUTION OF SEMIVOLATILE ORGANICS IN THE SPIKED TREATMENT SYSTEM

	Final Effluent Concentration (µg/l)	Overall Percent Removal	Percent in Primary Sludge	Percent in Waste Activated Sludge	Percent in Final Effluent	Total Mass Recovered (percent)
PESTICIDES/PCB's						
Arochlor 1254	< 2.9	98	51	60	2	113
Heptachlor	< 2.3	93	33	35	7	75
Lindane	25.8	45	12	8	55	75
Toxaphene	< 2.9	98	31	27	2	60
PHENOLS						
2,4-dimethylphenol	< 0.9	99	0	0.5	1.1	1.6
Phenol	< 13.5	95	4.4	0.8	5	10.2
Pentachlorophenol	< 6.3	19	26	5	81	112
PHTHALATES						
Bis(2-ethylhexyl)phthalate	11.3	79	63	39	21	123
Butylbenzylphthalate	< 1.3	96	119	7	4	130
Diethylphthalate	< 1.2	97	7	9	3	19
Dimethylphthalate	< 0.8	98	0.3	2	2	4.3
Di-n-butylphthalate	< 2.7	94	39	11	6	56
Di-n-octylphthalate	< 4.8	83	91	43	17	151
POLYNUCLEAR AROMATIC HYDROCARBONS						
Acenaphthene	< 1.2	97	41	4	3	48
Anthracene	< 0.9	97	67	5	3	75
Benz(a)anthracene	< 0.6	98	67	18	2	87
Chrysene	< 1.2	97	75	13	3	91
Fluoranthene	< 1.9	94	84	13	6	103
Fluorene	< 0.7	98	51	3	2	56
Napthhalene	< 0.7	99	22	0.5	1	23.5
Phenanthrene	< 1.1	97	59	1	3	63
Pyrene	< 2.0	94	107	7	6	120

On a mass flow basis the phthalates were unevenly distributed between the two sludge streams; more of the compounds were found in the primary sludge. The results indicate that diethylphthalate and dimethylphthalate are more biodegradable than the other compounds studied in that class. Since these two compounds have the simplest structures, this finding is not surprising.

The PAHs are the least polar of all the compounds except for PCBs. One would, therefore, assume their preferential adsorption to the solids, which are removed in primary treatment. As a class, the PAHs concentrated in the primary sludge to the greatest degree. In contrast, only low amounts of the PAHs were found in the activated sludge samples.

This research did demonstrate that a typical primary-activated sludge plant significantly reduced the concentrations of the 22 extractable organic priority toxics; however, certain compounds, most notably lindane, bis(2-ethylhexyl)phthalate, phenol, and di-n-butylphthalate, passed through in the activated sludge effluent in relatively significant concentrations. The impact of these low-level residuals on the aquatic environment would be a function of many site-specific factors, such as ambient water quality and dilution flows. Furthermore, although some compounds were biodegraded, many of the chemicals removed were present in the sludges in very high concentrations. The fate of these materials in the solids handling processes is not known at this time, and additional research must be conducted to provide answers to this pressing question.

Removal of Purgeable Organics

A study on the removal of volatile organics by conventional primary-activated sludge treatment was also completed. The results presented represent a preliminary assessment of the available data. The operations of the two pilot systems for the volatile studies exhibited stable and straightforward operation. The water quality performance for the treatment sequences indicated the pilot systems provided good treatment. The operations data and performance in both control and spiked systems indicate essentially the same operation for both systems with an SRT of about 5 days.

The 16 volatile organics in the initial phase of the work were nominally spiked into the experimental treatment system at 50 µg/l. Higher spiking concentrations of 200 µg/l were also employed. Organic analysis, in addition to the usual wastewater and sludge process streams, included gas phase analyses of the air streams from the aeration basin. The results presented in Table 5 are based upon the 11 sets of data collected during the 50 µg/l period.

The selected volatile organics are usually present in the Cincinnati raw wastewater in analytically measurable quantities (0.2 µg/l). The spiking substantially increased the concentrations of the organics to improve the evaluation of the removability by the treatment plant.

The initial evaluation of the data (Table 5) reveals excellent removals for most of the purgeable organics with 90 percent or better removals. Two organics, 1,1,2-Trichloroethane and Dibromochloromethane exhibited relatively low removals of approximately 70 percent with substantial residuals in the secondary effluent. The combination of tetrachloroethylene and tetra-

TABLE 5. DISTRIBUTION OF VOLATILE PRIORITY POLLUTANTS IN THE SPIKED TREATMENT SEQUENCE

	Final Effluent Conc. (µg/l)	Percent Found in Primary Sludge	Removal by Primary Clarifier (percent)	Percent Found in Waste Act. Sludge	Removal by[a] Treatment Sequence
Methylene Chloride	2.4	3.2	9.9	0.04	98.9
1,1-Dichloroethene	0.2	0.04	77.9	0.07	< 99.5
Chloroform	2.5	0.52	18.7	0.23	99.4
Carbon Tetrachloride	0.2	0.08	66.9	0.16	98.7
1,2-Dichloropropane	5.1	2.76	5.2	0.06	96.1
Trichloroethylene	1.3	17.54	10.4	0.09	97.0
1,1,2-Trichloroethane	24.0	0.74	8.1	0.83	65.6
Dibromochloromethane	8.9	0.16	25.7	0.09	72.7
Benzene	0.3	15.63	52.9	0.09	99.4
1,1,1-Trichloroethane	0.8	0.39	75.2	0.01	99.4
Bromodichloromethane	0.5	0.02	NR	0.16	95.7
Chlorobenzene	0.9	10.62	25.4	0.03	99.8
Tetrachloroethylene and Tetrachloroethane	10.2	19.42	NR	0.23	95.0
Toluene	0.6	9.42	2.5	0.06	97.1
Ethylbenzene	0.2	33.29	5.1	0.25	88.9

a = Removals based on mass balance.
NR = Not removed.

chloroethane, and 1,2-Dichloropropane, while exhibiting nearly 90 percent removals or better, passed through the treatment system into the secondary effluent with concentrations greater than 5 ug/l.

The results also reveal that only modest amounts of the purgeable toxics were transferred to the plant's sludges. This is an important observation since many of the purgeable organics would be generally leachable into groundwater if the sludges were placed in landfills or on the land for final disposal.

Metals Removal and Impact

The metals studies involved two separate operational periods; an evaluation of the distribution and removal of indigenous metals in the Cincinnati raw wastewater by the control treatment system (12) during the semivolatile organics studies, and subsequent studies in which four specific metals--Cd (13), Pb (14), Hg (15), and Cr (16)--were spiked into the small pilot systems in a sequence of increasing concentrations of the individual metal. The studies on the individually spiked metals included an unspiked control system in order to compare the impacts of the increasing metal concentrations with the conventional plant operation and performance.

The pilot plant operating conditions and overall plant performance were the same as those in semivolatile organics study. The pilot system exhibited very stable operations and very satisfactory plant performance with the background metals in the influent wastewater. The metals concentrations in the Cincinnati raw wastewater are typical of U.S. cities with substantial industrial contributions. The Cincinnati metals concentrations, however, are all less than the maximums reported for 20 municipal treatment plants (4).

The metals concentrations for plant process streams and the primary and secondary sludges, except for the soluble Cu, Mg, and Hg (concentration below or near the detection limit), were presented as log normal probability distributions. Summary highlights of the data analyses for the metals overview work are presented in Tables 6 and 7.

Table 6 summarizes the metals removals, computed from the mean concentrations, for the primary clarifiers, activated sludge process, and the overall system. As one would predict, there was no significant removal of either Ca or Mg. The ambient Hg concentrations were too low to permit the quantitation of removal in a proper manner. The total removals for the remainder of the metals range from 19 percent for As to 80 percent for Cu and are representative of typical plant removals.

Mass balance calculations were performed using the mean contaminant concentrations and the pilot plant operating data. The results of the mass balances are summarized in Table 7. For the 12 metals and arsenic, the average closure on the mass balance was 94.2 percent for the total system, and 94.0 percent on the primary clarifier. Cd and Fe were the two metals with the worst closures. Examination of the Cd data indicates that the concentration in the waste activated sludge is probably low, while the problem with iron appears to be low concentrations in both sludges.

TABLE 6. METALS REMOVAL IN CONTROL TREATMENT SYSTEMS

Metal	Influent (mg/l)	Pri. Eff. (mg/l)	Removal by Pri. Clar. (percent)	Act. Sludge Eff. (mg/l)	Removal by Act. Sludge (percent)	Total Removal (percent)
Ag[a]	8.0	9.0	0.0	5.0	44.0	37.5
As[a]	20.6	16.0	22.3	16.7	0.0	18.9
Ca	85.0	81.0	5.8	81.0	0.0	5.8
Cd[a]	20.9	17.0	18.7	7.9	53.5	62.2
Cr	0.63	0.51	19.0	0.34	33.3	46.0
Cu	0.80	0.57	28.8	0.16	71.9	80.0
Fe	4.29	2.44	43.1	1.01	58.6	76.5
Hg[a, b]	2.0	2.0	-	2.0	-	-
Mg	17.6	18.0	0.0	17.9	0.0	0.0
Mn	0.65	0.55	15.4	0.40	27.3	38.5
Ni	0.45	0.27	40.0	0.18	33.3	60.0
Pb	0.88	0.58	34.1	0.11	81.0	87.5
Zn	1.24	1.28	0.0	0.46	64.1	62.9

[a] Micrograms/liter.

[b] The Hg concentration is near the detection limit for the metal and removals cannot properly be calculated.

TABLE 7. METALS MASS BALANCES IN CONTROL TREATMENT SYSTEM

Parameter	Percent of Influent in		Mass Balance Primary Clarifier	Percent of Influent in		Mass Balance Total System
	Primary Effluent	Primary Sludge		A.S. Effluent	Waste A.S.	
Ag	112.3	10.7	123.0	61.1	34.6	106.4
As	97.3	0.3	97.6	78.4	17.9	96.5
Ca	93.7	2.9	96.6	91.5	0.0	94.4
Cd	80.7	3.1	83.9	36.7	9.9	49.8
Cr	80.6	15.4	96.0	52.5	59.1	126.9
Cu	70.9	18.4	89.3	19.4	53.0	90.8
Fe	56.6	5.7	62.3	22.9	23.4	52.0
Hg	< 100.0	< 0.4	< 100.4	< 99.5	< 10.9	100.8
Mg	101.8	1.7	103.5	98.8	3.2	103.8
Mn	84.2	15.0	99.2	59.8	38.6	113.4
Ni	59.8	15.3	76.1	38.8	23.3	77.4
Pb	65.6	17.4	83.0	12.2	40.5	70.1
Zn	102.7	17.7	120.5	36.0	36.1	89.9
Cl	102.5	0.6	103.1	105.1	2.5	108.2
F	116.9	0.1	117.0	113.4	2.0	115.5
SO_4	96.8	0.1	96.9	97.5	0.3	98.0
SiO_2	103.1	0.7	103.8	86.2	11.0	97.9
TDS	93.6	0.8	94.4	87.8	4.4	92.9

Soluble salts of the metals Cd, Pb, Hg, and Cr (+6) were added to the small pilot systems, and the spiking concentration periodically increased to ultimately stress the treatment process to failure. A parallel control system without the spike was operated indentically during each metal study. The operating conditions at each metal concentration level were maintained relatively constant, but were varied during the course of the spiking sequence such that the control system was essential to assess the metal impact on performance. While the principal operating control, the sludge retention time (SRT), was varied from below 2 to over 12 days, most of the spiking operations were performed with about 5- to 8-day SRT. The data analyses have been completed for three of the metals. The chromium evaluation is ongoing.

In addition to the conventional operations and water quality parameters, the spiked and control systems were monitored for effluent turbidity and their mixed liquors were microscopically examined using dark field and 645X. A series of photomicrographs was taken to document changes in microbiota as the metal concentration was increased.

The experimental results were used to evaluate the principal effects of the metals addition on the plant operation as a function of increasing metal concentration. The studies also provided process and system metal removals, metal partitioning to the plant's sludges, and passthrough of the metal from the treatment plant; all as functions of the spiked influent metal concentration.

Limited highlights of the results are presented in Tables 8 and 9 and Figures 1 and 2. Table 8 presents the effects of three of the metals on the activated sludge process. Significant deterioration of the overall plant performance generally requires substantial metals concentrations in the influent to the biological process, well above typical background metals concentrations.

The metals concentrations correlations, usually as a function of system or process influent concentration, exhibited reasonable correlation coefficients (Table 9) and can be used to predict process or system performance for the removal of metals. Representative graphical presentations, of the lead concentrations in the spiked system's process and sludge streams as a function of the influent metal concentration and for the concentration correlations on the spiked lead, are provided in Figures 1 and 2. An additional observation is that the metals removal efficiencies for the spiked metals were higher than those observed for the indigenous metals. This observation may be principally related to an improvement in analytical accuracy at higher concentrations.

Toxicity Removal

Even with extensive removability data and occurrence concentrations on the individual toxics, health or ecosystem effects from the complex mixture of metals in municipal or industrial wastewaters and treated effluents are very difficult to evaluate. A biomonitoring approach to assess health and ecosystem impacts and to supplement the specific occurrence and removal data is being evaluated in the toxics studies.

TABLE 8. SUMMARY OF EFFECTS OF METALS SPIKING ON THE ACTIVATED SLUDGE PROCESS

Effect Observed	Metal Concentration, mg/l, Entering Activated Sludge Process		
	Cd	Pb	Hg
Breakthrough of metal into secondary effluent	2.0	continuous	continuous
Increase in effluent COD	4.1	-	-
Increase in SVI	8.6	0.76	.16
Inhibition of nitrification	8.6	1.7	12.5
Decrease in respiration rates	10-20	-	3.3
Decrease in colonial stalked ciliates	8.6	30.5	-
Significant turbidity increase	30.5	30.5	3.3
Floc destabilization and complete process failure	-	71	-

TABLE 9. REMOVAL CORRELATIONS FOR Cd, Pb AND Hg

I. Activated Sludge Effluent -y vs Primary Effluent -x:

Cadmium (mg/l):

$\log y = 0.731 \log x - 0.964$ $\quad r = 0.89$

Lead (mg/l):

$\log y = 1.060 \log x - 1.070$ $\quad r = 0.93$

Mercury (µg/l):

$\log y = 0.890 \log x - 0.618$ $\quad r = 0.95$

II. Primary Sludge -y (Mg/Kg) vs Influent Wastewater -x (mg/l):

Lead:

$\log y = 0.31 \log x + 2.34$ $\quad r = 0.86$

Mercury:

$\log y = 1.248 \log x - 1.756$ $\quad r = 0.96$

III. Waste Activated Sludge -y (mg/kg) vs Primary Effluent -x (mg/l):

Cadmium:

$\log y = 1.005 \log x + 3.077$ $\quad r = 0.96$

Lead:

$\log y = 1.140 \log x + 2.350$ $\quad r = 0.97$

Mercury:

$\log y = 0.653 \log x + 1.254$ $\quad r = 0.90$

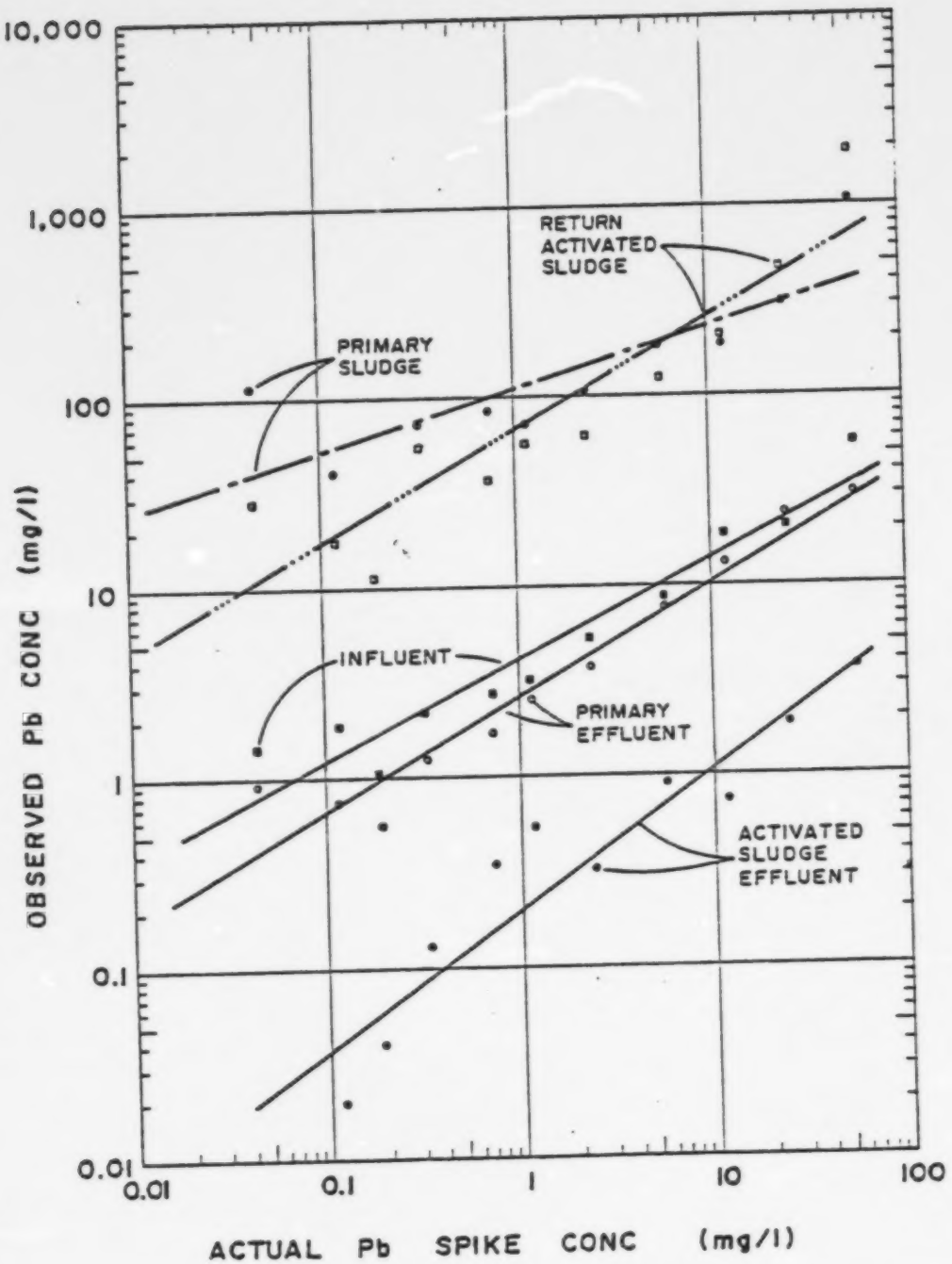

Figure 1. Lead concentrations in spiked system.

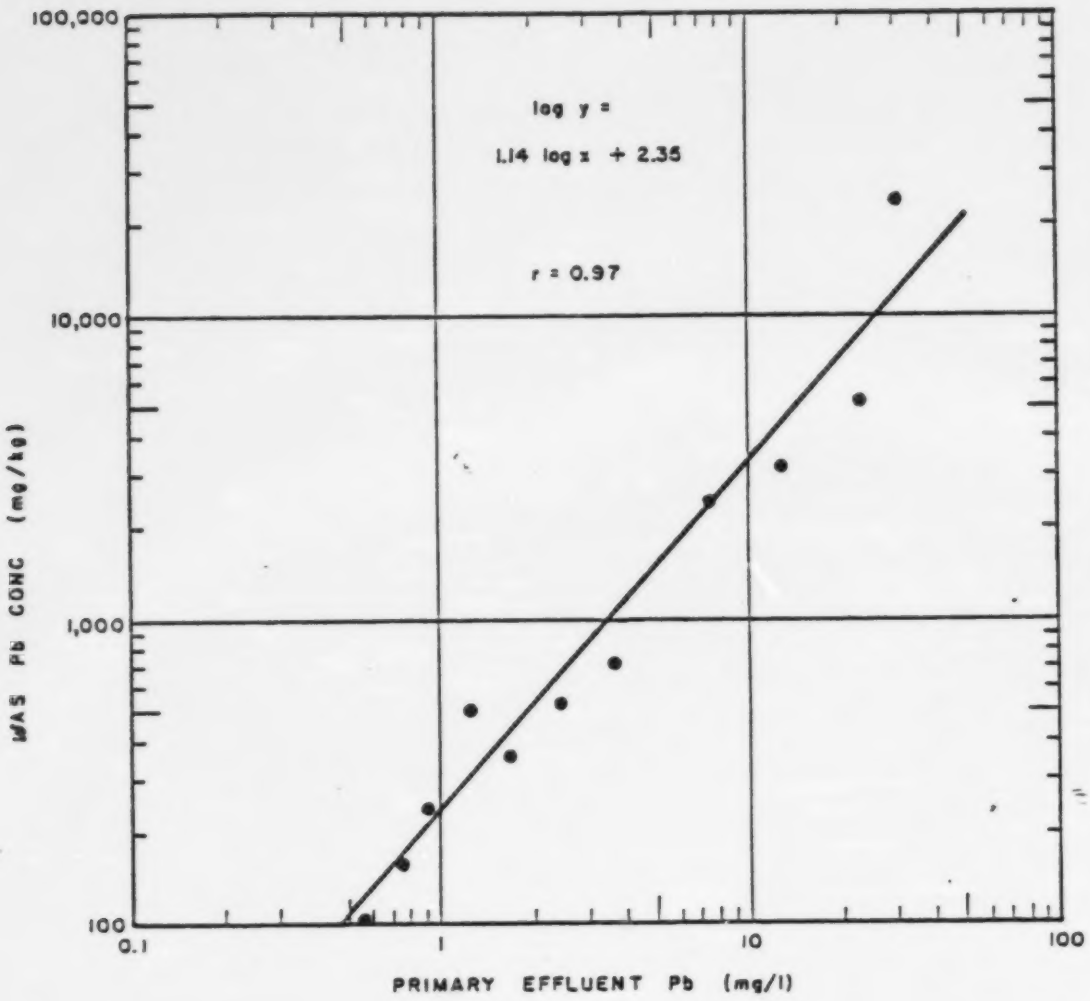

Figure 2. WAS Pb concentration as a function of the primary effluent Pb concentration.

The EPA's Newtown Fish Toxicology Station in Cincinnati is assessing removal of toxicity from the spiked and control raw wastewater during conventional treatment in the toxics studies. The Fish Toxicology Station is using fathead minnows, rainbow trout, and Daphnia magna as testing targets in 96-hour static (LC50) acute toxicity tests for the fish and in 48-hour static (EC50) acute toxicity tests for Daphnia magna. The acute toxicity reductions by the treatment systems are based upon the reduction of lethal units measured in the influent and effluents from the treatment systems or processes. The lethal units are calculated from:

$$LU = \frac{100\%}{\text{LC 50 or EC50 as percent wastewater}}$$

Chronic toxicity residuals are also determined in the wastewater or effluents using the early-life-stage (ELS) chronic test on fathead minnow embryos. The chronic exposures with various dilutions of wastewater are initiated with eggs less than 24 hours old and continue through 30 days after hatching. The effects on embryo survival, and larvae survival and growth, are measured to estimate chronic toxicity of the wastewater to the fish embryo-larvae as a representative ecosystem organism.

Finally, an assessment of mutagenicity reduction by the treatment systems has been recently initiated using the Ames Test as the indicator. The work with the Cincinnati Health Effects Research Laboratory involves extracting the raw wastewater, primary effluent, secondary effluent, and chlorinated secondary effluent from an unspiked treatment system with methylene chloride. The extraction separates the bacteria and viral cells in the wastewater from the toxic organics. The organic extracts are solvent transferred to dimethyl sulfoxide (DMSO), and the DMSO extracts are used in the Ames test to assess the reduction in mutagenicity by the treatment processes. Results are not yet available on this work.

The ecosystem toxicity work was performed during the semivolatile organics studies. The operating conditions, water quality levels in the wastewaters and effluents, and specific toxics concentrations encountered in the semivolatile studies describe the wastewaters used by the Fish Toxicology Station.

The representative results to date on the acute toxicity reductions are summarized in Table 10. The unspiked raw wastewater exhibited moderate acute toxicity which increased when the priority pollutants were added. The conventional treatment system essentially eliminated the acute toxicity from the wastewater in the control (unspiked) study. Conventional treatment also reduced, but did not eliminate, the acute toxic effects of the effluent from the spiked wastewater system. The initial study also revealed that dechlorination of chlorinated secondary effluent essentially prevented increased acute toxicity from chlorination of the secondary effluent.

TABLE 10. ACUTE TOXICITY (96-HOUR) OF MUNICIPAL WASTEWATER BEFORE AND AFTER CONVENTIONAL WASTEWATER TREATMENT: FATHEAD MINNOW - PHASE I

Sample Date	LC-50, Percent		Percent Toxicity Reduction	LC-50, Percent		Toxicity Reduction
	Unspiked Influent	Unspiked Effluent		Spiked[a] Influent	Spiked[a] Effluent	
12-14-79	-	100	-	-	36.1 (28.5-43.4)	-
12-19-79	-	64.4 (59.2-70.5)	-		22.3 (18.7-25.8)	-
1-16-80	30	100	100	4.6 (3.5-16.2)	13.1 (10.0-16.0)	65
1-22-80	11.0 (9.3-12.5)	100	100	2.7 (2.2-3.3)	16.1 (13.6-19.0)	83
4-2-80[b]	9.3 (7.9-11.2)	100	100	9.5 (8.1-11.1)	35.5 (30.3-43.3)	73
4-15-80[b]	30	100	100	4.5 (3.2-5.8)	6.6	32
4-24-80[b]	10.2 (8.5-13.0)	100	100	4.3 (3.3-6.5)	9.4 (7.9-11.5)	55
5-5-80[c]	18.5 (16.5-20.7)	100	100	5.8 (4.8-7.6)	30	81
5-13-80[c]	10.1 (98.3-11.1)	100	100	6.5 (5.6-7.6)	30	78
6-4-80	20.6 (17.8-25.3)	100	100	1.9 (1.0-2.3)	8.0	76

[a] Spiked samples - mixtures of 22 organic priority pollutants in pilot treatment system.

[b] Slight excess control fish mortality in samples.

[c] Samples were 24-hour composites - others were grab samples.

NOTE: Toxicity reduction calculations based on lethal units $\left(LU = \frac{100}{LC50}\right)$. Numbers in parentheses are 95% confidence limits.

The embryo-larvae chronic testing for five percent and lower concentrations of unchlorinated final effluent from the spiked system (Table 11) revealed no statistical difference in the embryo/larvae survivals or in the growth of the larvae-juveniles compared to the control. However, in other results the application of chlorination/dechlorination to the final effluent produced a statistically significant reduction in larvae-juvenile survival and in growth rate at the 5 percent concentration level of plant effluent in diluent water.

Prediction of Plant Performance

The representative removability data from conventional primary-activated sludge treatment and the performance indicators for treatability (octanol/water partition coefficient, etc.) have been used by experienced personnel in the Municipal Environmental Research Laboratory to estimate the removal efficiencies in various less-than-secondary treatment systems. A typical example for the pesticide class of toxics is presented in Table 12. The estimates were developed by best professional judgment. The observed removal efficiencies of representative organics in primary-activated sludge treatment were modified, based upon knowledge of the gross pollutant treatment capabilities of the individual alternative plants and the pertinent performance indicators (Table 3) from treatability studies, to estimate the removals in the alternative treatment processes.

Confirmation of these estimates and the development of models to permit selection by less experienced professionals of the appropriate technology for site-specific control of toxics in municipal wastewater treatment remain as long-range goals.

Planned Research on Removability

Ongoing and planned research in toxics removability and related residual disposal includes:

- The removal and fate of representative toxics (spiked organics and indigenous metals) in five less-than-secondary treatment systems for marine discharges:
  a. Chemical treatment in primary
  b. Primary and filtration
  c. Primary and high rate trickling filter
  d. Primary and high rate activated sludge (one day SRT)
  e. Two-stage facultative lagoon
- The fate and impact of toxics (spiked organics and indigenous metals) on landfill disposal of municipal sludges and municipal sludge with municipal solid waste.
- The fate of metals in incineration of sludge.

TABLE 11. SURVIVAL AND GROWTH OF EARLY-LIFE STAGES OF FATHEAD MINNOWS EXPOSED TO ACTIVATED-SLUDGE EFFLUENT IN SPIKED SYSTEMS

Nominal concentration %	Embryo survival %	Larval-juvenile survival (%) at 30 days	Juvenile weight (mg) mean ± S.D. at 30 days	Juvenile length (mm) mean ± S.D. at 30 days
5.0	88	-	113 ± 38	20.6 ± 2.4
	82	93	117 ± 36	23.5 ± 1.5
2.5	92	97	167 ± 49	23.1 ± 2.4
	86	90	155 ± 36	22.9 ± 1.7
1.2	86	100	167 ± 49	23.3 ± 2.5
	88	93	178 ± 49	24.1 ± 2.2
0.62	88	-	197 ± 53	24.5 ± 2.8
	88	90	207 ± 60	24.7 ± 2.7
0.31	88	97	207 ± 55	24.5 ± 2.3
	90	93	196 ± 64	24.4 ± 2.7
0.16	86	100	183 ± 57	23.9 ± 2.1
	92	80	200 ± 35	24.6 ± 1.5
Control	90	93	196 ± 53	24.3 ± 2.1
	88	100	188 ± 63	24.5 ± 2.5

TABLE 12. ESTIMATION OF REMOVALS OF PESTICIDES BY VARIOUS LESS THAN SECONDARY TREATMENT PLANTS

Process	Estimated % Removal			
	Toxaphene	Acrolein Isophorone	Other[a] low log P	High[b] log P
Screening, Coarse	5	5	5	15
Screening, Fine Sedimentation (Primary)	30	15	15	50
Filtration of Coarse Screened Raw Sewage Filtration of Primary Effluent	40	20	20	70
Coagulation/Precipitation Dissolved Air Flotation	40	25	25	80
High Rate Trickling Filter	60	80	30	80
High Rate Activated Sludge	70	80	30	80
Facultative Lagoon Aerated Lagoon	95	90	40	90
RBC	90	90	40	90
Aerobic Fluidized Bed of Primary Eff. Sequential Batch Reactor Conventional Activated Sludge	95	95	45	95

[a] Low Log P

- Toxaphene
- Chlordane
- Alpha-endosulfan
- Beta-endosulfan
- Endosulfan sulfate
- Heptachlor epoxide
- Alpha-BHC
- Beta-BHC
- Gamma-BHC (Lindane)
- Delta-BHC
- Acrolein
- Isophorone

[b] High log P

- Aldrin
- Dieldrin
- DDT
- DDE
- DDD
- Endrin
- Endrin Aldehyde
- Heptachlor

- The impact and removal of the spiked inorganics (Cu, Zn and CN on the conventional primary-activated sludge treatment.

- The toxicity (health effects) reduction in conventional primary secondary as measured by cytotoxicity and mutagenicity in in-vitro mammalian cell bioassays.

- The acute and chronic (ecosystem) toxicity reduction as measured by various aquatic bioassays on the less-than-secondary treatment systems.

SUMMARY

The research on toxics control in municipal wastewater has revealed the following overall findings.

- Conventional primary-activated sludge treatment is generally effective in removing toxic substances, typically achieving better than 90 percent removal of organics and from 60-80 percent removal of the indigenous metals. A number of the toxic substances, however, pass through into the treatment plant final effluent in sufficient concentrations which, based upon EPA's proposed water quality standards, may present a possible environmental hazard.

- Individual inorganics, pesticides, and PAHs pass through treatment plants in sufficient amounts, with sufficient frequency, to produce a possible environmental concern for a substantial fraction of treatment plants. Halogenated aliphatics may represent a concern when limited dilution of a wastewater discharge occurs before a water supply use.

- In general, other individual priority organics pass through treatment plants in amounts that may produce potential environmental concerns in only a few plants. The substantial numbers of these individual organics, while observed in only a few individual plants, may produce, as an aggregate, a site-specific environmental concern for a substantial fraction of treatment plants.

- An important overall observation from the work on toxic substances is that the treatment of the domestic/industrial wastewater has exhibited remarkable stability over a wide range of operating conditions and produced consistent and excellent treatment of the wastewater, even when spiked with large doses of metals or toxics organics. In contrast, earlier experience in treating domestic wastewater over similarly wide ranges of operating conditions has revealed operating areas where the growth of organisms such as Spaerotilus natans predominate in the activated sludge process and contribute to poor settling characteristics of the sludge. One possible explanation to the treatment stability in the toxic studies is that the background of toxic contaminants in the Cincinnati wastewater reduces the biological competitiveness of the exposed poorly settling organisms.

- In any event, the EPA work indicates that the central municipal wastewater treatment plant potentially represents a cost-effective alternative to industrial pretreatment for the control of many toxic substances. Use of the treatment plant for toxics control, however, requires evaluation of the impact of the toxics on the

sludge handling and final disposal processes. In addition, the use and practical management of the central, municipal treatment plant for toxicity control would benefit from the availability of suitable biomonitoring tests for determining the removal of overall toxicity, both acute and chronic, for health and ecosystem protection.

Finally, important research challenges in the use of the central municipal plant for control of toxics are:

- Development of modeling capabilities to permit the selection of cost-effective treatment systems for site-specific control of the wide varieties of toxics entering municipal wastewater treatment plants.

- Development of in-plant operational changes or treatment enhancements to improve plant performance and reliability.

- Development, by water quality researchers, of improved criteria for establishing realistic plant removals and residual disposal requirements.

REFERENCES

1. "Innovative Technology - Meeting the Challenge of the 80's." U.S. EPA, Office of Water Programs (WH-547), Washington, DC 20460 and Office of Research and Development (MERL), Cincinnati, OH 45268, September 1980.

2. Natural Resources Defense Council (NRDC) et al. vs. Train 8 ERC 2120 (DDC 1976).

3. DeWalle, F.B., et al., "Presence of Priority Pollutants in Sewage and their Removal in Sewage Treatment Plants," Draft Final Report, Grant R-806102, Municipal Environmental Research Laboratory, U.S. EPA, Cincinnati, Ohio.

4. Feiler, H., "Fate of Priority Pollutants in Publicly-Owned Treatment Works, Interim Report." Report No. EPA 440/1-80/301 (1980).

5. Tabak, H.H., et al., "Biodegradability Studies with Organic Priority Pollutant Compounds." JWPCF, 53, 1503-1518 (October 1981).

6. Warner, H.P., et al., "Determination of Henry's Law Constants of Selected Priority Pollutants." U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio, April 1980.

7. Dobbs, R.A. and Cohen, J.M., "Carbon Adsorption Isotherms for Toxic Organics." U.S. EPA 600/8-80-023, Municipal Environmental Research Laboratory, Cincinnati, OH 45268

8. "Treatability Manual, Vol. I - Treatability Data," U.S. EPA, Cincinnati, Ohio, January 1980.

9. Hannah, S.A., et al., "Removal of Uncommon Trace Metals by Physical and Chemical Treatment Processes." JWPCF, 49, 2297-2309 (November 1977).

10. Petrasek, A.C., et al., "Fate of Toxic Organic Compounds in Wastewater Treatment Plants." U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio. Submitted to JWPCF, December 1981.

11. Petrasek, A.C., et al., On-going work at the U.S. EPA Test and Evaluation Facility, Municipal Environmental Research Laboratory, Cincinnati, Ohio.

12. Petrasek, A.C., "Distribution and Removal of Metals in a Pilot-Scale POTW," Internal Report, U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio. Submitted to JWPCF, August 1982.

13. Petrasek, A.C., "Inhibition of the Activated Sludge Process by Cadmium," Internal Report, U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio.

14. Petrasek, A.C., "Inhibition, Removal, and Partitioning Interactions Between Lead and the Activated Sludge Process," Internal Report, U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio.

15. Petrasek, A.C., Mercury Report in preparation, U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio.

16. Petrasek, A.C., Chromium Report in preparation, U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio.

17. Horning, W., et al., "Organic Priority Pollutant Toxicity Reduction by Conventional Wastewater Treatment. Draft Report, U.S. EPA, Environmental Research Laboratory-Duluth, Newtown Fish Toxicology Station, Cincinnati, Ohio.

18. Pickering, Q.H., Report in Preparation, Newtown Fish Toxicology Station, Cincinnati, Ohio.

19. Federal Register, 44 (233), December 3, 1979, "Guidelines Establishing Test Procedures for Analysis of Pollutants, Proposed Regulations," pp. 69526-69558.

20. "Interim Methods for the Measurement of Organic Priority Pollutants in Sludge," U.S. EPA, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, September 1979.

21. Warner, J.S., et al., "Analytical Procedures for Determining Organic Priority Pollutants in Municipal Sludge," EPA-600/2-80-030, Municipal Environmental Research Laboratory, U.S. EPA, Cincinnati, Ohio, March 1980.